5

Technology In Water Management

This chapter highlights the present status and anticipated development of water management technologies. Review of water management technologies provides an important foundation for evaluating water management options described in later chapters of the Bulletin. For example, it is a common public perception that seawater desalting will solve most of California's future water problems. However, the current and reasonably foreseen state of desalting technology suggests that it will be used to meet relatively small, specialized needs due to its high cost. This chapter presents some case histories of selected technology applications and illustrates a few innovative examples.

Demand Reduction Technologies

Technological advances have improved urban and agricultural water use efficiency throughout the State. Future advances are expected to affect landscape irrigation, residential indoor water use, interior commercial, institutional, and industrial water use, and agricultural water use. Since the purpose of the Department's Bulletin 160 series is to assess water supply benefits, it is that aspect of demand reduction that the Bulletin addresses. Demand reduction technologies may provide additional benefits, such as reducing water treatment costs, reducing fish entrainment at water supply

The city of Santa Barbara's desalter was operated during the drought in 1992 and is now on standby status.

diversion structures, or reducing nonpoint source runoff. These other benefits are recognized in the Bulletin's options evaluation process, as described in Chapter 6.

Landscape Irrigation Technology

New irrigation control system technology can save water by setting irrigation cycles to account for changes in such factors as soil moisture and ET. New technology includes both retrofit devices and redesigned irrigation controllers.

Residential landscape irrigation systems often include sophisticated control devices such as electronic timers and electric solenoid-controlled valves. This increased sophistication does not always translate into water savings because homeowners often lack information on landscape plant water requirements. Consequently, many residential irrigation timers are permanently set to meet maximum summer season water requirements. A 1997 study by Utah State University showed that significant water savings could be achieved by retrofitting existing residential irrigation control systems with inexpensive (about $100) soil moisture-sensing devices. The devices are placed inline between the existing timer and valves and override a planned irrigation cycle when adequate soil moisture is available. Study results showed that the devices reduced landscape irrigation water use by an average of 10 percent. Follow-up questionnaires revealed that over 70 percent of the study participants observed that their lawns were as green or greener than before installation of the device.

New irrigation system controllers for the commercial, industrial, and institutional sectors are programmed for irrigation schedules based on normal year ET rates, and are adjustable to account for deviations from normal year ET. Some of the most advanced controllers can be automatically adjusted to current ET rates using telecommunication pager technology to access weather data from automated weather stations. Rainfall sensors represent an inexpensive method to automatically terminate irrigation controller programs during precipitation.

Residential Indoor Water Use Technology

Technological advances in residential indoor water use efficiency have come primarily from redesigning plumbing fixtures to meet new State and federal standards. Future efficiencies will come from improved fixtures and installation of more water-efficient home appliances. In addition, new technology to characterize residential water use may yield data allowing more accurate forecasts of components of urban water demand. This information would help allocate demand reduction program resources.

Previously, the breakdown of residential water use was estimated from water meter data and assumptions about the water use of various fixtures and appliances. However, a 1995 study in Boulder, Colorado, showed that detailed information on water use patterns could be gathered through analysis of data obtained from data loggers attached to residential water meters. The traces have sufficient detail to identify flow signatures of individual fixtures and appliances. The technique also provides information to differentiate between indoor and outdoor water use. Based on the success of the Boulder study, a larger study was organized by the American Water Works Association Research Foundation. The goal of this study is to collect information from 1,200 homes in 12 cities, for two 2-week periods—one period in the winter and another in the summer. The information will be sorted into its major end use components: toilets, showers, baths, faucets, dishwashers, washing machines, and leaks. Preliminary results are shown in Table 5-1. These data will be combined with information from a survey of study participants to construct a residential water use model. A final report on the study is scheduled for publication in 1999.

Plumbing Fixtures. State law requires all toilets sold or installed in California to use no more than 1.6 gallons per flush. These standards have pushed traditional gravity operated toilets to the limit of acceptable operation. The performance of gravity operated toilets is limited to the flow rate achieved through the bowl under the force of gravity, placing a limit on the potential for reducing the amount of water used in each flush.

Pressure-assisted toilets use pressurized flow, in conjunction with siphon action, to give acceptable

TABLE 5-1

Distribution of Residential Indoor Water Use

Component	*Average Use (%)*
Toilet	26
Washing Machines	23
Shower/Bath	20
Faucets	15
Leaks	13
Dishwasher	1
Other Uses	2

operation with less flushing water. The increased flow rate (more than 70 gpm compared to about 25 gpm for gravity designs) provides greater force to remove solids from the bowl and hastens the start of the siphon action. In addition, the surge of water from a pressure-assisted toilet is more effective at pushing waste through the drain line.

In the past, use of pressure-assisted technology was limited to the commercial sector due to high costs and increased noise. Current residential designs are less expensive than previous models and only slightly noisier than gravity toilets. Pressure-assisted toilets range in price from $220 to $815, compared to $65 to $575 for gravity toilets. Future residential designs may use 0.5 gallons or less per flush.

Washing Machines. Horizontal-axis washing machines (front loading washing machines) use significantly less water than traditional vertical-axis, central agitator machines. Rather than fully immersing the clothes, the tub of the washer rotates through a horizontal axis in alternating directions to lift and tumble the clothes through a pool of water. Recent studies show that these washers use about 25 to 35 percent less water than central agitator models.

Currently, horizontal axis washing machines produced by American manufacturers range in price from about $700 to $1,100. Models by some European manufacturers are considerably more expensive. Prices are expected to decrease to within about $200 of central agitator models as the market grows. A recent survey of appliance retailers showed the residential market for front loading washers could increase from about 2 percent at present to between 5 to 20 percent over the next five years.

Water Heaters. Hot water demand systems save water by either eliminating the need to drain cold water sitting in the pipe between the water heater and the plumbing fixture, or by reducing the distance between the heater and fixture. Demand systems are designed in two basic configurations: central storage tank and tankless systems. Central storage tank systems are based on traditional water heater and plumbing systems, modified with the addition of a valve to open a loop back to the hot water tank, and a pump to push the cold water back to the water heater while drawing hot water into the pipe. When hot water reaches the fixture, the loop closes and the hot water exits the fixture. Tankless systems, also known as instantaneous or on-demand water heaters, heat water only when needed. They can be located near the plumbing fixture to reduce the amount of cold water that must be displaced for hot water to reach the fixture. Because they do not store hot water, tankless systems save energy by eliminating standby losses.

Water savings depend on the amount of water to be displaced before hot water reaches the fixture (or the amount of water that would have been displaced, in the case of tankless systems). Measurements by the California Energy Commission show that about two times the pipe volume between the water heater and the fixture must be replaced before hot water reaches the fixture, due to heat lost to the pipe. A 1996 study of potential water savings in Southern California showed that hot water demand systems could save approximately 30 gpd per unit.

Interior CII Water Use Technology

Plumbing Fixtures. The water savings potential of 0.5 gpf toilets also applies to the commercial sector. In addition, while State law requires that urinals use no more than an average of 1.0 gpf, this water requirement could be further reduced or eliminated through the use of waterless urinals. Waterless urinals attach to

High efficiency horizontal axis washing machines are being used in commercial applications, but are just becoming available for home use. A check of large appliance dealers in 1998 showed that two brands of horizontal axis washers were commonly in stock, at prices ranging from $700 to $1,100. Comparable standard washers cost from $100 to $600 less. Some utilities are offering their customers rebates on the order of $100 to $150 for purchasing the horizontal axis machines.

standard plumbing stubs, but require no flushing water to operate.

Water savings from waterless urinals depends on the frequency of use and the flushing water requirement of the fixture that is replaced. A 1996 study in Southern California showed potential savings from about 11 gpd per fixture in office buildings to about 55 gpd per fixture in airports and movie theaters. In 1995, the U.S. Navy equipped sample bathroom facilities at the Naval Air Station North Island in San Diego with waterless urinals. The study found that replacement saved about 45,000 gallons of water per year, with a pay-back period of about 3 years. Based on the success of the trial, more than 200 waterless urinals were installed at the station. To date, the urinals remain in operation and perform well when maintained according to manufacturer recommendations.

Cooling Towers. The largest use of water in the industrial sector is for cooling. Water is used to cool heat-generating equipment, manufactured products, and food products and containers in canneries. The most water-intensive cooling method is once-through cooling, where water contacts and lowers the temperature of a heat source, then is discharged to waste. Recirculating cooling tower systems reduce water use by using the same water for several cycles.

The majority of cooling towers in California are recirculating evaporative systems, where the temperature of the cooling water is reduced through evaporation. As cooling water is recycled through the tower, the salt concentration increases. Salt build-up must be managed to avoid scaling on condenser tubes, which results in reduced heat transfer efficiency. Blowdown is the release of some of the circulating water to remove the suspended and dissolved solids left behind due to evaporation. Make-up water is added in place of the blowdown to reduce the total dissolved solids. Water savings can accrue by minimizing blowdown or by converting to a dry cooling process based on air heat exchangers.

Evaporative cooling towers are used by a wide range of industries.

Blowdown can be minimized by treating the recirculating water with sulfuric acid or ozone (to control scaling and biological fouling), by mechanical filtration of solids, and by the use of conductivity sensors and automatic valves to precisely control the blowdown/makeup process. Savings can be maintained through regular calibration of the conductivity sensors. A 1996 study conducted for MWDSC suggested that the majority of potential cooling tower water savings in Southern California could be realized through the addition and/or calibration of conductivity controllers. Water savings estimates ranged from about 400 to more than 900 gpd per site.

Air heat exchangers use fans to blow air past finned tubes carrying the recirculating cooling water. The Pacific Power and Light Company's Wyodak Generating Station in Wyoming uses dry cooling to eliminate water losses from cooling water blowdown and evaporation. The processed steam is condensed by routing it through finned carbon steel tubes as fans force air, at a rate of 45 million cubic feet per minute, through an 8 million square foot finned-tube surface. This technique results in a water requirement of 300 gpm, compared to about 4,000 gpm of make-up water for equivalent evaporative cooling.

Agricultural Water Use Technology

Future technological advances in irrigation systems and irrigation scheduling are expected to result in more efficient agricultural water use.

Irrigation Systems. Many terms are used in describing the performance of irrigation systems, but the two most important are DU and SAE, defined in Chapter 4. The accompanying sidebar defines several agricultural technology terms used throughout this section. Irrigation experts generally agree that an 80 percent DU is achievable by all irrigation systems and is an upper limit for existing systems. With today's systems, SAEs of more than 73 percent indicate under-irrigation, potentially resulting in a reduction of

Definition of Irrigation Terms

- Distribution Uniformity: A measure of the variation in the amount of water applied to the soil surface throughout an irrigated area.
- Seasonal Application Efficiency: The water beneficially used for ETAW and cultural practices divided by applied water.
- Intake Opportunity Time: The amount of time that applied irrigation water is in contact with the soil.
- Allowable Depletion: Depth of water needed to bring soil moisture to field capacity—a measure of how dry the soil is allowed to become before an irrigation is applied.
- Reference Evapotranspiration (ET_o): The ET of well-watered 4 to 6 inch tall turf.

crop production and an increase in soil salinization. Whether a gravity or pressurized system, a well-designed and well-managed irrigation system appropriate to a field's terrain, soil, crop, and flow constraints can achieve the maximum DU and result in high SAE, provided the irrigation water supply is of adequate quality and is available when needed at the proper rate of delivery.

Adoption of new irrigation technology to reduce applied water must result in a reduction of deep percolation, tailwater runoff, ET, or leaching requirement. Reduced deep percolation and tailwater runoff could be achieved by improving in DUs and irrigation management. Evapotranspiration could be reduced by minimizing losses from surface evaporation, or by intentional underirrigation with no loss in production or quality. Reducing the leaching requirement (the amount of water used to leach salts from the soil) is not a goal because insufficient leaching results in salinization of the soil, rendering it less productive and consequently reducing water use efficiency.

Gravity, or surface irrigation, systems use the soil surface to spread and move water on and over a field. The major types of gravity irrigation systems used in California—furrows, border-strip, and level basin—are discussed in the sidebar. The field is optimally rectangular, with the water entering the field from the highest side. The water moves over the surface of the soil, eventually covering the area intended for irrigation, and infiltrates the soil to replenish soil moisture. The rate of infiltration varies by soil type and time (a sandy soil has a much higher infiltration rate than a clay soil). All soils have a maximum infiltration rate at the beginning of irrigation. The longer the water is in contact with the soil, the more the infiltration rate decreases; in some soils it decreases to almost zero.

Important factors for achieving high DUs are intake opportunity time and soil infiltration rate. The IOT varies within an irrigated field. On furrow systems, the part of the field closest to the source of water usually has the highest IOT. For high DUs, the IOT within a field must have a high uniformity. In addition, soil will affect the DU. Different soils with the same IOT will have different infiltration rates. The more nonhomogeous the soil, the more soil infiltration rates will vary, resulting in a lower DU.

Irrigation timing, applying the correct amount of water, and having a high DU are important considerations for achieving high SAE. With most surface systems, the grower must decide how dry the soil can become (its allowable depletion) before an irrigation is applied. The grower's decision is based on the field, irrigation system design, crop, soil depth, and other factors. If the soil has an AD of 3 inches, irrigation should occur when the soil in the field has dried to that level. The amount of water applied over the field should be more than 3 inches, because water cannot be applied with a DU of 100 percent. Irrigating before reaching the AD could result in an over-application of water, and a lower SAE. Irrigating after reaching the AD might result in an under-application, and an overly high SAE, which is not desirable because plant stress may occur.

Pressurized, or piped, irrigation systems use pipelines and water emission devices to discharge water into a field and onto or under the soil surface. Water is pressurized using a pump and is usually passed through a filter to reduce the chance of clogging the emission devices. The water is distributed from a main pipeline system and sub-mains to lateral pipelines in the cropped field. Water flows from the emission devices as either a spray or a very small continuous stream. As the water meets the soil, it infiltrates to replenish soil moisture.

Pressurized systems are very different from surface systems. The performance of surface systems depends upon soil infiltration rates, IOT, and the amount of water applied. With pressurized systems, DU is constant and depends on the hardware design and maintenance. The DU will not change, unless pipeline leaks or clogging of devices occur, or winds distort the spray pattern. One of the most important design considerations for achieving high DUs is pressure regulation, as flow rates change with pressure. Excessive pressure variations in the design will result in a low DU.

The most important considerations for achieving high SAE with pressurized systems are applying the correct amount of water during an irrigation, and maintaining a high DU. Since a pressurized system can apply any amount of water with the same uniformity, the amount of water needed to replenish the crop root zone must be determined before the irrigation. Then the irrigation can be operated for the correct amount of time to apply the required water. The major types of pressurized irrigation systems used in California—sprinkler and micro-irrigation—are discussed in the sidebar.

Irrigation Scheduling. All irrigation systems require proper scheduling to achieve high SAEs. To develop an optimized irrigation schedule, the grower considers several factors: allowable or desirable crop water stress, the soil's water holding capacity within the crop root zone, water availability and/or delivery constraints, amount of effective rainfall, and application rate. With this information, along with soil moisture determinations, plant stress indices, and/or estimates of crop ET, a grower can develop a water budget schedule. The water budget compares crop ET with soil AD, allowing the grower to decide when and how long to irrigate.

Soil moisture is monitored many ways. Subsurface soil samples can be taken and visually inspected to estimate the moisture status. Soil moisture can be estimated with mechanical devices such as tensiometers or with electrical resistance devices such as gypsum blocks that rely on the change in electrical conductivity of water in the device. A neutron probe, another moisture-sensing device, measures the amount of neutrons reflected from water molecules in the soil.

Gravity (Surface) Irrigation Systems

Furrow Systems

Furrow is the most common gravity system, and is used for field crops, truck crops, trees, and vines. Channels or corrugations are cut or pressed into the soil of a field, usually one furrow between planted rows of crops. Efficient furrow systems have a slight grade, sloping from the head of the field where water enters the furrows to the bottom of the field. Water is delivered to the furrows using an earthen ditch and siphon tubes, gated pipe, or underground piping and above ground valves. In furrow systems, only the soil in the channel is wetted. Between 20 to 50 percent of the soil surface in a furrow irrigated field usually comes in contact with the irrigation water.

To irrigate sloping furrow systems efficiently, tailwater is allowed to run off the end of the furrows. A tailwater recovery system is needed to reapply this water, either on the same field or on another field. Efficient management requires a relatively high flow at the beginning of the irrigation, to get the water down the furrow quickly, then the flow is cut back to reduce tailwater. With furrow systems, high DUs can be achieved when the advance time (the time it takes the water to move from the top of the field to the end) is relatively short compared to the total time of irrigation.

Furrow systems can be designed and operated to achieve good SAEs for a range of ADs, except for very small ADs. The AD changes as the root zone changes. The early season irrigation of annual crops will not be as efficient as later season irrigations, because the early season AD would be small (shallow root depths), while the later season AD would be large (deep roots). Infiltration rates are typically higher soon after planting and lower later in the season.

Technologies and actions to optimize DUs and increase SAEs for furrow systems include:

- Dragging torpedoes (heavy metal cylindrical devices) within a furrow to smooth and compact the soil surface will decrease the advance time. This is most effective for early season irrigations, where the soil surface is rough due to tillage, and the soil intake rate is high.
- Shortening the length of the furrow will result in decreased advance time. (Shortening furrows increases the number of furrows, which can also result in less planted acreage and an increase in the cost of irrigation.)
- Laser leveling of fields to achieve a uniform slope, and a steeper slope (if practical), will decrease the advance time.
- Using surge irrigation, a technique where short term opening and closing of valves provides water to the furrows, resulting in the water "surging" down the furrow. (This technique is better suited to some soil types than others.) This technique will improve the uniformity of IOT in a furrow. It requires a surge valve designed for this application, and can easily be automated.
- Reducing the flow rate in each furrow after the water has reached the end of the furrow is essential to reducing the amount of tailwater produced.
- Using a properly planned and designed tailwater recovery system, along with efficiently using the captured tailwater on the same field or other irrigated fields.

Border-Strip Systems

Border-strip systems are generally used for alfalfa and pasture, but can be used on field crops and trees and vines. A field is divided into a number of strips, usually between 20 to

continued ...

100 feet wide. Low levees, or borders, divide each strip. Each strip has a slight slope from the head of the strip to the bottom, and ideally little or no slope between the sides. Water is delivered to each strip using an earthen ditch and siphon tubes, gated pipe, or underground piping and above ground valves. Usually all the soil surface in the strip, other than that in the borders, comes in contact with irrigation water.

A relatively large flow of water is directed into each strip during irrigation. The time it takes for the water to reach the end of the field is the advance time. When the water is between 60 to 90 percent of the way down the strip, the water is shut off, and the water already in the strip continues to move down the strip. The time it takes for the water to recede from the soil surface (from the top of the strip to the bottom) is the recession time. To achieve a high DU, the advance time must be very similar to the recession time, resulting in a uniform IOT over the strip. Generally, a border-strip system is designed and operated to have a small amount of tailwater, which requires a tailwater recovery system for reducing applied water. Border-strip systems can be designed to have a high DU and can achieve a high SAE, but only for a specific AD. Border-strip systems are well suited to crops with a constant deep root zone, such as alfalfa, pasture, trees, and vines.

Technologies and actions for border-strip systems to optimize DUs and increase SAEs include:

- Modify the advance rate to match the recession rate by adjusting the flow rate, changing border spacing, and using laser leveling to achieve a uniform slope and minimize cross slope.
- Use a properly planned and designed tailwater recovery system, and use the captured tailwater efficiently on the same field or on other irrigated fields.

Level Basin Systems

Level basin systems can be used on alfalfa, pasture, trees, vines, and field crops. The size of each basin is variable and depends upon soil infiltration rate and flow rate of water. Basins can vary from small (50 x 50 feet) to large (10 or more acres). There should be little or no slope within a basin. Earthen berms are built up on all sides of the basin. Water is delivered into each basin from pipelines and valves for smaller basins or from lined or unlined ditches with large gates. Normally, level basins are designed to have no tailwater. To achieve a high DU, the basin must be level, the flow of water must be high enough to cover the soil surface in a very short time (without any soil erosion from the flow), and the soil should be homogeneous.

Technologies and actions to optimize DUs and increase SAEs for level basin systems include:

- Use laser leveling to achieve a precise grade.
- Minimize soil variability within a basin. Large basins can be subdivided into smaller basins with uniform soil characteristics.

A side roll, wheel move sprinkler system.

Moisture content can also be estimated by dielectric sensors, devices that measure the dielectric content of a soil.

Plant stress indicator devices include pressure bombs and infrared thermometers. A pressure bomb is used to determine the turgor pressure within the cells of a plant's leaf, which provides information on the plant's moisture status. Infrared thermometers are hand-held devices used to measure plant canopy temperature. Plants can control water loss by regulating the stomatal openings in their leaves. Monitoring plant canopy temperatures with this device aids in determining if crop stress is occurring, and can indicate the status of soil moisture.

Crop ET estimates are developed using either evaporation pans or weather information. Class A evaporation pans are commonly used for measuring evaporation. The pans, constructed of galvanized steel or aluminum, are situated in the center of a large irrigated turf area. The pan station includes devices to measure rainfall, temperature, wind speed, and relative humidity. Evaporation is measured by monitoring the change in height of the water in the pan. The evaporation readings are multiplied by crop coefficients to estimate ET of a specific crop.

Many growers use automated weather station data for determining crop ET, such as the California Irrigation Management Information System. CIMIS is a

Pressurized (Piped) Irrigation Systems

Sprinkler Systems

Sprinkler systems are the most common type of pressurized systems and can be used for almost all crops. There are many different sprinkler head designs with flow rates that can vary from 10 gpm to less than 1 gpm. The spacing of the sprinkler heads in the field depends upon the flow rates and the radius of the area where the spray contacts the soil. To achieve high DUs, systems for field and truck crops are designed to space sprinkler heads close enough so that there is the proper amount of overlap of their wetted areas. Sprinkler systems for tree crops do not generally depend on overlap.

To achieve high DUs, a system must be designed to have minimal pressure variation, which ensures uniform flow rates from the sprinkler heads. Sprinkler nozzles must be maintained, because clogged or partially clogged nozzles lower DU, and worn nozzles will change flow rates, resulting in larger variations in pressure in the system. The application rate must be the same or less than the soil's infiltration rate. There are many variations in sprinkler systems used in California.

Permanent Systems. Permanent systems use underground pipelines. Risers connect to an underground lateral, usually with a sprinkler head attached less than a foot from the surface. These systems are commonly used for orchard irrigation (under tree), but when connected to taller risers they can be used for vines.

Solid Set Systems. Solid set systems use above ground aluminum pipelines, usually in 30 foot sections. Short risers connect the aluminum laterals to sprinkler heads. With a solid set system, the irrigation system covers a complete field. The system may stay in the field for the whole growing season, and be removed before harvest, or may be used only for germination or transplant establishment of vegetable crops. These systems are used mainly for field and truck crops.

Hand Move Systems. Hand move systems are similar to the solid set systems, using the same aluminum pipelines, but do not normally cover a whole field. After an irrigation, the sprinkler laterals are disconnected from the sub-mains, and moved by hand to the next location in the field. After each irrigation, the laterals are systematically moved to the next location. These systems are usually designed for each part of the field to receive irrigation water every 7 to 14 days. These systems are used on field crops, truck crops, and orchards.

Wheeled Systems. Wheeled systems have the lateral, risers, and sprinkler heads all mounted on wheels that can be moved throughout the field during the irrigation season. Side roll systems are designed to be stationary during the irrigation. After the irrigation, they are moved (using an on-board engine) to the next location.

Linear Move Systems. Linear move systems have the lateral, risers, and sprinklers mounted on pipes between large wheeled towers. The system continuously travels down the field during irrigations. The water is usually supplied to the system via a canal parallel to the travel of the system.

Center Pivot Systems. Center pivot systems are similar in structure to linear move systems, except instead of the lateral traveling down the field, it travels in a circle in the field. One end of the lateral is fixed in the middle of the field, where the water enters the lateral. The entire lateral rotates around this pivot (which is usually a well), and continuously moves during irrigations.

Low-Energy Precision Application Systems. LEPA systems are similar to linear move sprinkler systems, except that they have drop tubes from the lateral to the soil surface instead of sprinkler heads. These systems are used in fields that have furrows, sometimes with small checks or dams in the furrow. The LEPA system travels perpendicularly to the furrows, and drop tubes emit water uniformly into the furrows.

continued...

Technologies and actions for sprinkler systems to optimize DUs and increase SAEs include:

- Minimize pressure variation within the system. Design sprinkler heads, nozzles, and spacings for the proper amount of overlap in spray. Ensure that application rates are lower than the soil infiltration rate, and that filtration is adequate. The sprinkler system must be properly maintained.
- To avoid spray losses, avoid irrigation during windy conditions, and ensure that pressures and nozzles are compatible to avoid misting.
- Where appropriate, use flow control nozzles.

Micro-Irrigation (Low Volume) Systems

Use of these systems increases each year. In many areas with trees and vines, they are the predominant method of irrigation. Low volume systems have many of the same components of sprinkler systems: pressurized water sources, filters, main pipelines, sub-mains, and laterals. The main difference is the devices that emit the water to the soil. These emit water at a very low flow rate (from 0.5 to 10 gallons per hour). There are two types of devices used, drip and micro-spray. With drip devices (emitters), water flows out as a constant stream (0.5 to 2 gallons per hour) directly to the soil. With micro-spray, the devices (spray heads) produce a spray (4 to 20 gallons per hour) over the soil surface. Other key differences between micro-irrigation systems and sprinkler systems are that the entire main and sub-main pipelines are usually underground rigid plastic pipe, the laterals are flexible plastic hose, and the filters are designed to remove much smaller particles to prevent clogging. Emitter and spray heads use small orifices, channels, or nozzles to regulate flow rates, and are subject to clogging by particulate matter and biological growth.

Drip system emitters are usually spaced 2 to 5 feet apart. Drip systems can be buried or placed on the soil surface. Emitter spacing is based upon the soil type being irrigated, with sandier soils needing a closer spacing, and clay soils using the greatest spacing. Drip systems are mostly used for orchards and vines, strawberries, and nurseries, but their use is increasing for vegetable crops. In these systems, the emitters are spaced much closer and are installed 8 to 18 inches below the soil surface.

Micro-spray systems use small plastic sprinklers or jets that spray water over the soil surface, creating a wetted area 12 feet or more in diameter. The droplet sizes are small compared to a sprinkler system, and the application rate is low. Micro-spray heads are connected to plastic lateral hoses, usually one hose per row of trees. These systems are not designed to wet the entire soil surface like a typical sprinkler system. These systems are used almost exclusively in orchards.

Drip and micro-spray systems can achieve high DUs if pressure variation is minimized. Because of the small nozzles and emitter pathways, partial or full clogging is always a potential problem, and can significantly reduce DU. These systems require regular maintenance to reduce clogging, including frequent flushing of pipelines and lateral hoses, and addition of chemicals (such as chlorine and acids) to kill bacteria and other biological growth and to reduce scale buildup. The systems require filtration and the filters need regular maintenance to ensure that they operate as designed.

Achieving a high SAE with these systems is dependent on maintaining a high DU and on proper irrigation scheduling. One advantage to these systems is that irrigation scheduling is more easily controlled than most sprinkler and surface systems. Flow can be started and stopped easily (providing the water delivery system can accommodate this), and they are easier to automate, even to the extent of using remotely sensed field information for making irrigation timing decisions.

Technologies and actions for optimizing DUs and increasing SAEs of micro-irrigation systems include:

- Ensure that pressure variation within the system is minimized, the filtration system is adequate, and prevent emitter clogging.
- Perform regular inspections of filters, emitters/spray heads, pressure levels, and tubing/pipelines, and provide regular maintenance, including filter cleaning and hose/pipeline flushing.
- Where appropriate, use pressure compensating emitters or microsprinklers.

repository of climatological data collected at 93 computerized weather stations throughout the State. CIMIS was developed by the Department and the University of California at Davis, and has been in operation since 1985. Weather data are collected daily from each weather station site and automatically transmitted to a central computer in Sacramento. Currently, the CIMIS computer receives over 25,000 requests for ET data annually, representing approximately 75,000 end users. The weather data (solar radiation, temperature, relative humidity, and wind speed) are used with a modified Penman equation to calculate ET_o. ET_o is used in irrigation scheduling to estimate plant ET, by multiplying ET_o by the appropriate crop or landscape coefficients.

Regulated deficit irrigation is a technique to reduce crop ET. Irrigation is reduced during a specific stage of the crop's growth, resulting in some crop stress at the time, but with little or no negative effects on production, quality, or on future growth. Research has shown that this management technique may be applied to some tree crops such as pistachios, almonds, and olives. This irrigation strategy may have its greatest value in drought situations, where a grower may be forced to under-irrigate.

Water Treatment Technologies

As discussed in Chapter 3, water quality is a critical factor in determining the usability and reliability of any particular water source. Traditional public health practices emphasize the need to use best available quality sources for municipal supplies and to implement source protection measures to maintain high quality raw water sources. Where raw water supplies are of less than pristine quality, greater reliance must be placed on treatment technology. Water recycling and desalting are becoming larger components of potential future supplies, especially for urban areas. To transform these lower quality raw water sources into reliable water supply options, the basic water treatment technologies described in this section are used. Application of these technologies to specific options (such as treating contaminated groundwater) is also outlined.

Description of Water Treatment Technologies

Activated Carbon Adsorption. Treatment by activated carbon adsorption is most applicable to organic contaminants. By bringing contaminated water in contact with activated carbon in granular or powdered form, the contaminants are adsorbed onto the carbon.

An evaporation pan with weather station in the background.

The process may be accomplished by batch, column, or fluidized-bed operations. Spent carbon may be regenerated or may be disposed of in accordance with regulatory requirements. In addition to the traditional use of activated carbon for taste and odor control and dechlorination, carbon adsorption is widely used for removal of volatile organic chemicals and synthetic organic chemicals.

Granular activated carbon adsorption is a unit process with a proven ability to remove a broad spectrum of organic chemicals from water. EPA considers GAC adsorption as the best available technology for removal of VOCs and SOCs. Powdered activated carbon has traditionally been used to control taste and odor in water, and is also used for removal of certain SOCs, especially pesticides. PAC, in combination with conventional water treatment technology, can provide acceptable levels of pesticide removal in surface waters. A typical application of PAC would be for seasonal removal of pesticides found in municipal treatment plant raw water supplies during wet weather. Some limitations to use of PAC include the potential need for large doses of carbon to achieve desired levels of treatment, and the resultant high sludge production.

Air-Stripping. This treatment technique removes VOCs from contaminated water. Countercurrent air-stripping in a packed tower is the most common process. The conventional configuration of a unit consists of a tower with water inflow at the top and air inflow at the bottom. The tower is filled with small diameter random packing. As clean air moves upward, the VOCs transfer from the water phase into the air phase. Treated water exits from the bottom, and the air containing VOCs is discharged from the top of the tower, either into the atmosphere or into a gas treatment system.

Since air-stripping transfers contaminants to the atmosphere, they must take into consideration allowable VOC emissions. In some parts of the State, such as in the South Coast Air Quality Management District, emissions are strictly regulated and additional treatment to reduce emissions to acceptable levels is needed. GAC adsorption may be used with air-stripping to control emissions from a packed-tower aeration system.

The closed-loop air-stripping process is an innovative extension of the traditional air-stripping technology. The closed-loop air-stripping process combines air-stripping with an ultraviolet photo-oxidation

This air stripping system at McClellan Air Force Base in Sacramento is being used to clean groundwater contaminated with solvents.

process to control VOC emissions. In this process, exhaust air is irradiated with UV radiation in a photo-oxidation chamber, and VOCs are destroyed. The end products are carbon dioxide, hydrochloric acid, and ozone. The treated air is recycled to the PTA unit.

Advanced Oxidation. In contrast to GAC or air-stripping, advanced oxidation processes can destroy organic contaminants rather than transferring them from one medium to another. Examples of AOPs include treatment with UV, ozone/hydrogen peroxide, and ozone/UV. AOPs provide more powerful oxidation and at faster rates than conventional oxidants such as chlorine. As a result, they can remove compounds which are not treatable with conventional oxidants. These oxidants can also reduce disinfection by-products created by processes such as chlorination. To date, much AOP work has focused on removing low-molecular weight solvents such as TCE and PCE from contaminated groundwater, and on reduction of DBPs.

Membrane Technologies. Membrane technologies include reverse osmosis, electrodialysis, microfiltration, ultrafiltration, and nanofiltration. RO, MF, UF, and NF are pressure-driven processes of barrier separation; electrodialysis employs electrical potential as the driving force. Membrane processes have been used for desalting, removal of dissolved organic materials, softening, liquid-solid separation, pathogen removal, and heavy metals removal. Other promising membrane technologies are membrane phase-contact processes. These processes are not pressure driven but remove contaminants by extraction into another phase, as do air-stripping and solvent extraction.

RO membranes permit water to flow through them while rejecting the passage of dissolved contaminants. This is based on the natural osmotic process where water passes through a semipermeable membrane from a solution of higher concentration to a lower one. In RO, a pressure greater than osmotic pressure is applied to the contaminated water. Water passes through the membrane but contaminants are retained. RO systems using newer membranes operate at about 250 psi for desalting brackish groundwater and up to 1,000 psi for seawater desalting.

Electrodialysis induces contaminant ions to migrate through a membrane, removing them from the water. In an electrodialysis unit, contaminated water is pumped into narrow compartments separated by alternating cation-exchange and anion-exchange membranes, selectively permeable to positive and negative ions. A variation of this process is called electrodialysis reversal. In electrodialysis, the electrical current flow is always in the same direction. In EDR, the electrical polarity is periodically reversed, which reverses ion movement and flushes scale-forming ions from the membrane surfaces.

MF, UF, and NF operate similarly to RO, but at lower pressures. More stringent drinking water regulations coupled with diminishing sources of pristine waters have stimulated interest in the use of membrane technologies in drinking water treatment. The use of low-pressure membrane filtration for municipal water treatment is a relatively new concept in the water industry, which has traditionally used membranes for removing salts or organic materials. MF operates at pressures ranging from 20 to 100 psi and is capable of removing micron-sized (10^{-6} m) materials. Colloidal particles are physically rejected by MF membranes. UF operates at pressures ranging from 3 to 150 psi and is capable of removing materials that are on the order of a nanometer in size (10^{-9} m) from water. Dissolved inorganic contaminants are not retained by MF and UF membranes. One of the most novel applications of low-pressure membrane technology is the removal of microorganisms such as coliform bacteria, viruses, *giardia,* and *cryptosporidium* from drinking water sources without using chemicals for primary disinfection. The efficiency of low-pressure membranes in removing particles from untreated water supplies has been well documented. MF and UF have shown to be capable of consistently reducing turbidities to less than 0.1 NTU, regardless of the influent turbidity level.

NF operates at pressures ranging from 150 to 300 psi and has characteristics between those of RO and MF. The capital cost of an NF plant is typically high compared to conventional treatment plants because of the cost of membranes and high-pressure equipment. Pilot and bench-scale studies have demonstrated that nanofiltration is effective in removing DBP precursors and SOCs such as pesticides. NF is also frequently used for water softening applications.

Ion-Exchange. The process passes contaminated water through a packed bed of anion or cation resins. The resin type is selected based on the contaminant to be removed. The treatment process exchanges ions between the resin bed and contaminated water. By displacing ions in the resin, contaminant ions become part of the resin and are removed from process water. During the ion-exchange process, the exchange capacity of the resin becomes depleted and needs regeneration to become effective. Sodium chloride brine is used to regenerate the resin. Ion-exchange is widely used for removing nitrates in groundwater and for removing some metals. It may also be used for water softening. Its effectiveness in removing radionuclides is being investigated in a number of full scale applications.

Chemical Precipitation. Chemical precipitation is used for removing heavy metals from water. The contaminants are precipitated from solution and removed by settling. There are several types of chemical addition systems including ones using carbonates, hydroxides, and sulfides. The carbonate system uses soda ash and pH adjustment. The hydroxide system is most widely used for removing inorganics and metals. The system uses lime or sodium hydroxide to adjust the pH upward. The sulfide system removes most inorganics (except arsenic). The disadvantage is that sulfide sludges are susceptible to oxidation to sulfate when exposed to air, resulting in resolubilization of the contaminants.

Biological Treatment. Biological treatment uses microorganisms to remove contaminants in water through metabolic processes. The process can be a suspended growth system, where the microorganisms and nutrients are introduced in an aeration basin as suspended material in a water-based solution, or a fixed-film system where the microorganisms attach to a medium which provides inert support. Biological treatment is used in municipal wastewater treatment and for treating water containing organic compounds such as petroleum hydrocarbons. Biological treatment is often used for remediation of leaking fuel tank sites, either above ground, or *in situ*.

Disinfection. This treatment inactivates pathogens in water. The most common disinfection process is chlorination, often used to treat wastewater and drinking water. Two relatively new disinfection processes applied in water recycling include UV radiation and ozonation. UV has recently been approved by the DHS for disinfecting recycled water. UV has been shown to be as effective as chlorine or ozone in reducing coliform bacteria and is more effective at virus removal. UV has the potential to be more cost effective than chlorine disinfection, and eliminates the DBPs and handling hazards associated with chlorination.

Innovative Treatment Technologies. Many innovative technologies are being used to treat contaminated groundwater at hazardous waste sites. These technologies typically combine basic processes with a few special techniques. In the future, these technologies may see broader application in groundwater recovery projects. Some examples of these technologies, primarily those applied at pilot or full scales, are covered below.

The EnviroMetal Process, a proprietary technology, treats groundwater *in situ* using reactive metal (usually iron) to enhance the abiotic degradation of dissolved halogenated organic compounds. A permeable treatment wall of the coarse-grained reactive metallic media is installed across a plume of contaminated groundwater, breaking down contaminants as they migrate through the aquifer. This technology has received regulatory approval for use in at least two industrial facilities in California for treating shallow plumes with elevated levels of VOCs.

Integrated vapor extraction and steam vacuum stripping removes VOCs, including chlorinated hydrocarbons, in groundwater and soil. The integrated system has a vacuum countercurrent stripping tower that uses low-pressure steam to treat contaminated groundwater, and a soil vapor extraction process to treat the soil. The stripper and the soil vapor extraction systems share a GAC unit to decontaminate the combined vapors. The technology has been used to treat TCE-contaminated groundwater and soil.

Steam-enhanced extraction uses injection wells to force steam through the soil to enhance vapor and liquid extraction thermally. The process extracts volatile and semivolatile organic compounds from contaminated soil and groundwater. The recovered contaminants are condensed or trapped by activated carbon filters. After treatment is complete, subsurface conditions are suitable for biodegradation.

Subsurface volatilization and ventilation technology uses a network of injection and extraction wells to treat subsurface organic contamination through soil vapor extraction and *in situ* biodegradation. A vacuum pump extracts vapors while an air compressor injects air in the subsurface. In most sites, extraction wells are placed above the water table and injection wells are placed below the groundwater level. Because it provides oxygen to the subsurface, the process can enhance *in situ* bioremediation.

The PACT wastewater treatment system is a proprietary technology that combines biological treatment and PAC adsorption to contaminated water. Microorganisms and PAC contact wastewater in an aeration tank. The biomass removes biodegradable organic contaminants, and PAC enhances adsorption of organic compounds. PACT systems treating up to 53 mgd of wastewater are in operation. This process is applicable to groundwater contamination from hazardous waste sites.

Capacitive deionization desalting is an experimental process being researched at Lawrence Livermore National Laboratory. It involves passing water through electrodes made of carbon aerogel and generating a small voltage differential between alternating positive and negative electrodes, thus drawing ions out of the solution. The ions are removed by electrostatic attraction and are retained on the electrode until the polarity is reversed. The ions are then captured with a small amount of water. Other dissolved materials such as trace metals and suspended colloids are removed by electrodeposition and electrophoresis. The process has been operating in a laboratory for over two years. Sodium chloride, sodium nitrate, and ammonium perchlorate solutions have been tested with excellent results. Electrode life has been acceptable in the laboratory, with electrodes operating for more than two years with little degradation. The electrodes appear to be regenerable with little loss of capability. Energy requirements appear less than current desalting technologies. Field testing has begun in Northern California, and will later be moved to Southern California.

Application of Water Treatment Technologies

Water Recycling. Recycled water uses include groundwater recharge, agricultural and landscape irrigation, wildlife habitat enhancement, industrial use, and recreational impoundments. Groundwater recharge and agricultural and landscape irrigation constitute the greatest uses of recycled water in the State. Table 5-2 lists some water recycling plants having a capacity of at least 10 mgd.

Indirect potable reuse of recycled water has been practiced for years through groundwater recharge programs. In Los Angeles County, the Montebello Forebay Groundwater Recharge Project began recharging the Central Basin aquifer with recycled water in 1962. Currently up to 60 taf/yr of recycled water percolates into the groundwater basin, from which it is later extracted for distribution in potable water systems. Water Factory 21 in Orange County and the West Basin Water Recycling Facility have been producing advanced treated recycled water for seawater intrusion barrier injection, with the majority of the injected water entering the groundwater and becoming part of the water supply.

As advanced treatment technologies become more cost-effective, and as public acceptance increases, augmentation of surface water supplies may become another application for recycled water. The San Diego water repurification program, discussed in the sidebar, would be the first example of planned, indirect potable reuse where repurified water is discharged directly into a surface reservoir without percolation or injection into groundwater. (Unplanned, indirect potable reuse occurs whenever treated effluent is discharged into a waterway upstream of another user's water supply intake.) Reservoir retention allows for additional monitoring of the repurified water prior to introduction to a potable water supply. Surface water supply augmentation projects are approved by DHS on a case-by-case basis.

TABLE 5-2

Water Recycling Plants with a Capacity of at Least 10 mgd

Name	*Capacity (mgd)*[a]	*Treatment Process*	*Type Of Reuse*	*Annual Supply (taf)*
San Jose Creek Water Reclamation Plant (Los Angeles County Sanitation District)	100	Primary sedimentation, activated sludge, coagulation, filtration and chlorination	Groundwater recharge, agricultural and landscape irrigation, and nursery stock irrigation	43.2
Donald C. Tillman Water Reclamation Plant (City of Los Angeles)	80	Primary sedimentation, activated sludge, coagulation, filtration, chlorination, and dechlorination	Recreational lake, wildlife lake, and Japanese garden	20.0
Fresno-Clovis Metropolitan Area Regional Wastewater Facilities	60	Primary sedimentation, trickling filter, and activated sludge	Agricultural irrigation	13.7
Los Coyotes Water Reclamation Plant (Los Angeles County Sanitation District)	37	Primary sedimentation, activated sludge, coagulation, filtration, and chlorination	Landscape irrigation, industrial reuse (process water, concrete mix, and dust control), and crop irrigation	5.9
West Basin Water Recycling Facility (West Basin Water District)	37	Coagulation, filtration, clarification and reverse osmosis (5 mgd), microfiltration and reverse osmosis (2.5 mgd)	Industrial use, landscape irrigation, and seawater intrusion barrier	8.4
Chino Basin Municipal Water District Regional Plant No. 1	32	Activated sludge, coagulation, filtration, chlorination, and dechlorination	Landscape irrigation and recreational lakes	1.7
City of San Diego North City Water Reclamation Plant	30	Primary sedimentation, activated sludge, coagulation, filtration, and chlorination	Landscape irrigation	3.0
Terminal Island Treatment Plant (City of Los Angeles)	30	Primary sedimentation, activated sludge, filtration, reverse osmosis, and microfiltration	Seawater intrusion barrier and industrial use	0[b]
Salinas Valley Reclamation Plant (Monterey Regional Water Pollution Control Agency)	30	Primary sedimentation, trickling filters, coagulation, filtration, and disinfection	Agricultural irrigation	13.2
Long Beach Water Reclamation Plant	25	Primary sedimentation, activated sludge, coagulation, filtration, and disinfection	Landscape irrigation, nursery irrigation, and repressurization of oil-bearing strata	5.1
City of Modesto Wastewater Quality Control Facility	25	Primary sedimentation, trickling filter, oxidation ponds, and chlorination	Fodder crop irrigation	14.4
Central Contra Costa Sanitary District Water Reclamation Plant	25	Primary sedimentation, activated sludge, UV disinfection, coagulation, filtration, and chlorination	Landscape irrigation, and light industrial	1.2

TABLE 5-2

Water Recycling Plants with a Capacity of at Least 10 mgd (continued)

Name	*Capacity (mgd)*[a]	*Treatment Process*	*Type Of Reuse*	*Annual Supply (taf)*
Los Angeles-Glendale Water Reclamation Plant (City of Los Angeles)	20	Primary sedimentation, activated sludge, coagulation, filtration, chlorination, and dechlorination	Landscape irrigation and industrial reuse	3.3
City of Bakersfield Wastewater Treatment Plant No. 2	19	Primary sedimentation and oxidation ponds	Crop irrigation	16.8
Laguna Treatment Plant (City of Santa Rosa)	18	Primary sedimentation, activated sludge, coagulation, filtration and chlorination	Fodder irrigation	9.3
Fairfield-Suisun Subregional Wastewater Treatment Plant	17	Activated sludge, coagulation, filtration, chlorination, and dechlorination	Sod farming and duck hunting marsh maintenance	2.4
Michelson Water Reclamation Plant (Irvine Ranch Water District)	17	Primary sedimentation, activated sludge, coagulation, filtration, and chlorination	Landscape irrigation, nursery irrigation, and toilet flushing	8.2
Whittier Narrows Water Reclamation Plant (Los Angeles County Sanitation District)	15	Primary sedimentation, activated sludge, coagulation, filtration, and chlorination	Groundwater recharge and nursery stock watering	9.4
San Jose/Santa Clara Water Pollution Control Plant	15	Activated sludge, filtration and chlorination	Landscape irrigation and industrial processes	7.5
Pomona Water Reclamation Plant (Los Angeles County Sanitation District)	13	Primary sedimentation, activated sludge, coagulation, filtration, and chlorination	Agricultural irrigation landscape irrigation, and industrial process	12.5
City of Visalia Water Conservation Plant	12	Primary sedimentation, trickling filter, activated sludge, and chlorination	Non-food crop irrigation	4.9
Valley Sanitary District Wastewater Treatment Facility (Riverside County)	12	Primary sedimentation, trickling filter, activated sludge, and oxidation ponds	Non-food crop irrigation	4.3
City of Bakersfield Wastewater Treatment Plant No. 3	12	Primary sedimentation, trickling filter	Agricultural irrigation	11.6
Desert Water Agency Wastewater Reclamation Facility (Riverside County)	10	Coagulation, filtration, and chlorination	Landscape irrigation	2.7
Water Factory 21 (Orange County Water District)	10	Coagulation, sedimentation, filtration, carbon adsorption (5 mgd), reverse osmosis (5 mgd), and disinfection	Groundwater injection for intrusion barrier	2.6
Lancaster Water Reclamation Plant	10	Primary sedimentation, oxidation ponds, and chlorination	Wildlife refuge and fodder irrigation	9.7

[a] One mgd equals 1,120 af/yr

[b] Expected to operate by 2000 with annual supply of 19 taf

San Diego Water Repurification Program

The City of San Diego, in conjunction with the San Diego County Water Authority, proposes to repurify 16 taf/yr of wastewater for indirect potable purposes. Results of pilot studies conducted by the agencies show that wastewater can be repurified to a level suitable for human consumption. The agencies would construct an 18 mgd wastewater repurification facility using state-of-the-art technology to treat recycled water from the City of San Diego's North City Water Reclamation Plant. The repurified water would be transported over 20 miles to the 90 taf San Vicente Reservoir, where it would be blended with imported raw water supplies and stored for a period of time. The blended water would eventually be conveyed via the existing El Monte Pipeline to the city's Alvarado Filtration Plant for traditional treatment before being delivered to the city's drinking water system.

Repurified water is based on a concept of multiple barriers. Recycled water from the North City Water Reclamation Plant, treated to levels acceptable for landscape irrigation and for other nonpotable purposes, would be treated further at the proposed 18 mgd wastewater repurification facility. The repurification process would include subjecting the recycled water to four more treatment processes — low-pressure microfiltration, reverse osmosis, ion-exchange, and ozonation. These treatment processes, while redundant in their functions, ensure reliability of the overall repurification system and produce an end product that would exceed current health and safety standards.

Pilot studies show that the City of San Diego could turn recycled water into an alternative drinking water source. The city is preparing an environmental document and has begun design of the project. The project is expected to begin operation in late 2002.

The California Potable Reuse Committee was formed in 1993 to study the viability and safety of indirect potable reuse. The committee, commissioned by DHS and the Department, developed six criteria that must be met before indirect potable reuse is allowed for augmentation of surface water supplies. (DHS has other proposed regulations and criteria for indirect potable reuse through groundwater recharge projects.) The criteria are:

(1) Application of the best available technology in advanced wastewater treatment with the treatment plant meeting operating criteria. Best available technology must include a membrane component with the functional equivalency of reverse osmosis.

(2) Maintenance of appropriate reservoir retention times based on reservoir dynamics.

(3) Maintenance of advanced wastewater treatment plant reliability to consistently meet primary microbiological, chemical, and physical drinking water standards.

(4) Compliance with applicable State criteria for groundwater recharge for direct injection of recycled water.

(5) Maintenance of reservoir water quality. In addition to meeting drinking water standards, recycled water used for reservoir augmentation shall be of equal or better quality than that in the storage reservoir on a constituent-by-constituent basis.

(6) Provision for an effective source control program.

The source control program is to include pretreatment/pollution prevention measures that prohibit the discharge of any substance which, whether alone or in combination with other wastewater constituents, causes or threatens malfunction or interference with the wastewater treatment process, constitutes a hazard to human health or safety, or affects the water quality of the potable storage reservoir.

Treatment criteria for reuse of municipal wastewater are mandated in Title 22 of the California Code of Regulations. These criteria specify the treatment level for specific reuse applications. Treatment technologies used for water recycling depend on the reuse application. For most nonpotable reuse applications at least secondary treatment is required. To achieve secondary treatment, conventional biological treatment processes such as activated sludge process, trickling filters, or oxidation ponds are used, followed by sedimentation and disinfection with chlorine.

Tertiary treatment, which is often standard for recycled water, is achieved by adding a filtration step after secondary treatment and before final disinfection. Two major types of filtration technology are applied in tertiary treatment plants: conventional and direct filtration. Conventional filtration, as defined in Title 22, includes coagulation, sedimentation, and filtration to condition the water. Conventional filtration technology requires that the filters be backwashed to prevent turbidity breakthroughs. The Title 22 back-

TABLE 5-3

Sample Desalting Plants

Site	*Owner*	*Capacity (mgd)[a]*	*Comments*
Brackish Water Desalting			
Arlington	Santa Ana Watershed Project Authority	6.0	Operational
Tustin	City of Tustin	3.0	Operational
Oceanside	City of Oceanside	2.0	Operational, being expanded
West Basin	West Basin MWD	1.5	Operational
Wastewater Desalting			
Water Factory 21	Orange County WD	5.0	Operational, being expanded
West Basin	West Basin MWD	5.0	Operational, being expanded to 7.5 mgd
San Diego	City of San Diego	1.0	Operational
Seawater Desalting			
Santa Barbara	City of Santa Barbara	6.7	Standby as drought reserve
Morro Bay	City of Morro Bay	0.6	Standby as needed
Marina	Marina Coast Water District	0.3	Operational
Santa Catalina Island	Southern California Edison	0.1	Operational

[a] One mgd equals 1,120 af/yr

wash requirements result in an equipment-intensive process. Direct filtration provides a cost-effective and convenient tertiary technology when secondary effluent quality is high. The technology will likely be incorporated in areas where effluent from residential areas provides the process water. Newer water recycling facilities use direct filtration as part of the tertiary treatment process. Direct filtration bypasses the sedimentation step. Continuously backwashed direct filtration technology is available, minimizing equipment needs.

Achieving the maximum use of tertiary treated water for landscape irrigation and other outdoor applications depends on the ability to store the treated water supply when it is not needed. Landscape irrigation demands, for example, have a wide seasonal variation in the State's inland areas. (Landscape irrigation demands also vary diurnally, with most sites demanding recycled water at night when supplies are at their lowest levels.) Groundwater recharge is often a cost-effective solution to meeting seasonal demand patterns, allowing the storage of relatively large quantities of recycled water without the capital cost investment associated with above-ground reservoirs.

Desalting. According to the International Desalting Association's inventory of worldwide desalting plants, the United States is second in usage of desalting in the world, with almost 1 maf/yr of installed capacity. (Only Saudi Arabia has more installed capacity.) In 1985, the United States had less than 7 percent of the world's capacity; by 1993, that figure had risen to nearly 15 percent. Common feedwater sources for desalting plants include brackish groundwater, municipal and industrial wastewater, and seawater. Costs of desalting increase with increasing feedwater salinity. Table 5-3 lists some larger desalting plants in California.

Reverse osmosis accounts for 89 percent of the installed capacity of desalting plants in California, including all the significant plants supplying municipal water supplies or recycling municipal wastewater. Reverse osmosis is likely to continue to dominate in California, given recent improvements in membrane performance. Reverse osmosis membranes have changed greatly in the last 20 years. Membranes are available to serve many purposes. This allows water suppliers to select and operate membranes specifically suited to the feedwater quality and the required product water quality. Membranes have developed into two principal classes.

The first class is the traditional reverse osmosis membrane which rejects all salt ions (as well as other dissolved constituents) equally. This process, also called hyperfiltration, is used on water requiring the removal of all classes of dissolved constituents. The second class of membrane processes is represented by MF, UF, and NF. For example, nanofiltration membranes reject larger dissolved ions such as calcium and

Seawater Desalting–
Marina Coast Water District

Marina Coast Water District is the primary water supplier for the City of Marina. MCWD relies on the Salinas Valley groundwater basin as its primary water supply source, as do other Salinas Valley urban and agricultural water suppliers. Overdraft of the Salinas Basin has caused seawater from Monterey Bay to migrate into two of the three aquifers underlying the coastal part of Salinas Valley. Seawater intrusion has rendered some groundwater unfit for use. MCWD has had to replace shallower wells with deeper wells to meet demands for potable water. MCWD investigated ways to diversify its water supply sources because of potential groundwater extraction limitations, and chose desalting as its preferred option.

MCWD completed construction of a reverse osmosis seawater desalting plant in 1997. The plant produces approximately 300,000 gpd of potable water (equivalent to 340 af/yr), and uses beach wells for seawater intake and brine disposal. A shallow production well drilled into beach deposits near MCWD's water treatment plant provides intake water for the desalting plant. Using a beach well to supply seawater minimizes the need for extensive pretreatment. Beach sands filter most of the suspended material in the seawater. The reverse osmosis system is a single stage system operated at 40 to 45 percent recovery rates.

The project produces a reject brine flow of about 450,000 gpd. An injection well in a shallow sand aquifer is used to dispose of the brine. Power requirements for the desalting plant are estimated at 5,000 kWh of electricity per acre-foot of water produced, or about 15 kWh for each 1,000 gallons of desalted water. Total capital costs for the desalting plant were about $2.5 million.

sulfate, along with equally large dissolved feedwater constituents. When used in a water softening role, they will remove calcium, magnesium, and sulfate from water, but allow sodium and chloride ions to pass through. Nanofiltration membranes are often used for water softening.

Advances in membrane technology have reduced operating pressures, increased flow rates, and increased salt rejection in typical reverse osmosis applications—thereby reducing treatment costs. As operating pressures have decreased, so have energy costs. Energy requirements have accounted for at least 50 percent or more of the operating costs of a reverse osmosis plant. New membrane materials have allowed more membrane area per module and higher productivity per square foot. Increased productivity of membranes and their longer life expectancy reduces the capital cost of the plant, reducing the cost of water. Increasing salt rejection provides better water quality. In the case of groundwater desalting, the high purity product water can be blended with raw water to meet the desired overall product water quality.

Treatment of Contaminated Groundwater

The selection of technologies for treating groundwater contamination depends on site conditions and the contaminants to be removed. Although there are a variety of options, no one technology is necessarily capable of responding to all conditions found at a groundwater contamination site. In practice, treatment technologies are sometimes used in combination to remediate contamination. For example, groundwater contaminated with nitrates and pesticides requires ion-exchange technology to remove the nitrates and GAC adsorption to remove the pesticides. Table 5-4 provides some examples of contaminated groundwater treatment sites. Treatment unit capacities at the locations shown range from 0.3 mgd to 4.1 mgd.

Some local agencies have integrated groundwater treatment plants into municipal distribution systems. The West Basin Municipal Water District for example, constructed a 1.5 mgd facility that uses reverse osmosis technology to remove elevated levels of dissolved solids from contaminated groundwater. The plant supplies about 1.5 taf annually of recovered groundwater to the district for municipal use and to Dominguez Water Corporation for municipal and industrial uses.

The Glenwood nitrate water reclamation plant, owned by Crescenta Valley County Water District, is a 3.7 mgd ion-exchange treatment plant. Treated groundwater from the plant is sold to Foothill Municipal Water District and MWDSC for municipal and industrial uses. The plant's eventual project yield will be about 1.6 taf annually. The City of Pomona operates a 15 mgd ion-exchange treatment plant, treating nitrate-contaminated groundwater from the Chino Groundwater Basin. At full capacity, the treatment plant supplies about two-thirds of the city's municipal water demand.

Some aquifers in California are contaminated because of past hazardous waste disposal practices. A number of these sites are undergoing remediation. Carbon adsorption, membrane filtration, air stripping, advanced oxidation processes, biological treatment, chemical precipitation, and innovative treatment technologies are examples of technologies used. For example, Aerojet General Corporation's manufacturing facility in Rancho Cordova operates a 6.5 mgd groundwater treatment facility which removes VOCs from the groundwater. The treatment facility has air-stripping towers and GAC adsorption units. Treated groundwater is reinjected into the aquifer through wells, and is also recharged via surface impoundments. Another example is Valley Wood Treating Company in Turlock, which uses pump-and-treat and *in situ* treatment techniques for chromium-contaminated groundwater. The company pumps groundwater and uses chemical precipitation for first stage contaminant removal. Next, a reducing agent is added to the treated water, which is then reinjected into the aquifer. The resulting reaction reduces chromium *in situ* and subsequently fixes residual chromium in the soil.

TABLE 5-4

Examples of Contaminated Groundwater Treatment Sites

Location	*Contaminant*	*Treatment*
Lodi	DBCP	GAC
Lodi	Pathogens	UV
Modesto	DBCP	GAC
Modesto	Nitrates	Electrodialysis
Fresno	DBCP	GAC
Fresno	TCE	Air-stripping
Clovis	DBCP	GAC
Monrovia	TCE	Air-stripping
Monrovia	VOCs	Air-stripping
San Gabriel Valley	VOCs	GAC

Water Supply/Flood Control Technologies

Inflatable Dams

Inflatable rubber, or fabric and rubber, dams and tubes have been used for years as weirs to impound water for water supply and flood control. Inflatable dams were developed and first used in the 1950s in the Los Angeles area. They were typically inflated with water. Since that time, construction materials and control systems have been improved and features have been added, such as fins to reduce vibrations during overflow. Air is now the preferred inflation medium. The manufacturers report that there are about 1,900 of these dams worldwide, with 50 in the United States.

Alameda County Water District's Rubber Dam No. 3 is a representative example of a modern inflatable dam. The 13-foot-high, 375-foot-long dam was

Remediation of Nitrate Contamination–City of McFarland

The City of McFarland in Kern County has a population of about 7,650 people. McFarland Mutual Water Company supplies municipal water. The company depends on groundwater for raw water supply and has four active wells.

Elevated levels of nitrates in MMWC's water were detected in the early 1960s. Many wells sampled showed nitrate levels exceeding the drinking water standard. Studies identified fertilizer application on agricultural lands as a major contributor to nitrates in the groundwater. MMWC abandoned two of its wells due to nitrate contamination and provided treatment for two wells to reduce nitrate levels to meet drinking water standards. Two deeper replacement wells were constructed to extract groundwater unaffected by nitrate or pesticide contamination.

In 1978, the MMWC received an EPA grant to study groundwater treatment alternatives, leading to the 1983 construction of a 1 mgd ion-exchange treatment plant. A second 1 mgd ion-exchange treatment plant for another well was constructed in 1983. The two wells supply about 20 af annually of treated water to McFarland and adjoining rural areas within the MMWC service area.

The plants' designs rely heavily on technology and practices used in the water softening industry. Plant location was dictated by the existing wells and distribution systems. Because there was no centralized distribution system, the plants had to be designed to operate from a single well. Well pumps operate on a demand basis, so the plants had to be able to operate automatically. The system was designed to accept water directly from the well, treat for nitrate removal, and allow treated water to flow directly into the distribution system. The ability of the process to adapt to quick start-up and frequent on-off operation was an important consideration in choosing it over reverse osmosis and biological treatment methods.

Remediation of Volatile Organics Contamination–McClellan Air Force Base

In 1981, McClellan AFB initiated soil and groundwater investigation as part of a Department of Defense program to identify and evaluate suspected contamination at military installations nationwide. Groundwater contaminants identified included VOCs, SVOCs, petroleum hydrocarbons, and trace heavy metals. Subsequent investigations revealed that contaminants had migrated off the base. At least one municipal well was abandoned because of contamination. In 1986 and 1987, 500 homes with private domestic wells to the west of the base were connected to the City of Sacramento's water system.

In 1987, groundwater extraction and on-site treatment began. The treatment involved an air stripper, with incineration and caustic scrubbing of the air stream, followed by carbon adsorption and biological treatment of the effluent. The treatment plant had a capacity of 1.44 mgd and discharged its treated water to Magpie Creek and to a wetland area under permits from the Central Valley RWQCB. Later, the biological treatment unit was removed when the concentration of ketones was low enough to be removed by the air stripper and carbon adsorption units.

In 1996, the air stripper and incinerator were replaced with a UV/ hydrogen peroxide system to remove volatile organics. The GAC is still in use. Operating and maintaining the new system is less expensive than the air-stripping and incinerating process, and the higher treatment efficiency reduces carbon use in the GAC units. Several more years of extraction and treatment of the groundwater will be required before the contaminated aquifer is restored to usable quality.

constructed in 1989 on Alameda Creek in the City of Fremont. The dam impounds a 154 af reservoir for direct groundwater recharge and diverts flows into adjacent spreading grounds in former aggregate pits. The air-inflated dam is bolted to a reinforced concrete slab that was constructed across the stream channel. To clear the leveed channel for flood flows, the dam is deflated by district personnel, or it automatically deflates slowly when overtopped by substantial flows. The dam is reinflated when stream flows subside to safe levels and any water-borne debris has passed the dam. These operations are much easier and safer than alternatives such as installing, tripping, and reinstalling hinged flashboards. A similar inflatable dam has been used in the Russian River at Mirabel since 1976, where water is diverted to percolation ponds.

The San Gabriel, Los Angeles, and Santa Ana River Basins also have similar devices. OCWD installed two large air inflatable rubber dams across the Santa Ana River (Imperial Highway Dam in 1992 and Five Coves

Remediation of Pesticide and Fertilizer Contamination–Occidental Chemical Manufacturing Facility

In the late 1970s, pesticide and fertilizer contamination was discovered in soil and groundwater at the Occidental Chemical Agricultural Products manufacturing facility near Lathrop. The primary contaminants found were dibromochloropropane, ethylene dibromide, and sulfolane. OxyChem removed or capped contaminated soil at the facility in 1981 and 1982. The groundwater remediation program began operation in 1982 and continues today. The original groundwater restoration system was designed to remove DBCP and EDB to 1 ppb. It consisted of five extraction wells, a 500 gpm treatment system, and two wells for deep injection of treated groundwater into an unusable confined aquifer. Sulfolane was not removed from the groundwater, but its injection to the aquifer was considered acceptable since the aquifer was designated unusable for domestic or agricultural purposes. SWRCB Resolution No. 88-63 in 1988, a 1989 revision of MCLs for DBCP and EDB, and a 1989 DHS maximum allowable level for sulfolane in municipal water resulted in more stringent treatment requirements. OxyChem made operational changes in the treatment system and added a biological treatment system in 1992 (microbial inoculation of the carbon treatment system) to remove sulfolane from the groundwater to comply with the new treatment standards of 0.2 ppb DBCP, 0.02 ppb EDB, and 57 ppb sulfolane. Two extraction wells were added, increasing treatment capacity to 600 gpm.

The groundwater restoration system was designed to treat the contaminated groundwater and to control the hydraulic gradient in order to prevent off-site migration of the contaminants. Several dozen monitoring wells were built to monitor the effectiveness of the system. Monitoring reports have shown reductions of contaminant concentrations and control of contaminant plume. However, it is anticipated that groundwater remediation will continue for many years.

Dam in 1993) to divert flows into groundwater recharge basins. The dams are deflated when flows exceed 1,000 cfs.

Other uses of inflatable dams have evolved. In 1988, PG&E replaced flashboards on its Pit No. 3 dam on the Pit River with 6-foot-high inflatable dams. USBR recently replaced two 18-foot-high by 100-foot-long drum gates on the crest of Friant Dam with Obermeyer gates. The gates are steel panels connected to the dam crest by hinges along their upstream edge, and are raised and lowered by air-inflated bladders. During the flood of January 1997, an inflatable rubberized berm was installed on the water side of the Sutter Bypass levee to provide the additional height needed to protect the levee from overtopping. Rubber berms of this type are used as cofferdams during construction projects in wet environments or as pollution containment devices.

Weather Modification

Since the early 1950s, California water users have practiced cloud seeding to augment precipitation, mostly along the western slopes of the Sierra Nevada and along the Coast Range. In 1996, there were 14 active cloud seeding programs operating in California. The goal of these programs is to increase water supply for hydroelectric power generation and for agricultural and municipal uses. Cloud seeding programs have potential legal and institutional issues associated with them, including claims from third parties who allege damages from flooding.

The principal elements of cloud seeding include selection of cloud masses, seeding materials, and methods to dispense the agents within the clouds. Several classes of seeding agents are available. Seeding agents are introduced into the clouds by either ground-based generators or aerial delivery systems.

Precipitation from clouds is a result of two different processes or mechanisms. The first is coalescence, whereby tiny cloud droplets collide to form larger droplets that eventually fall as rain. The coalescence process works at temperatures above freezing. The second mechanism requires ice particles and occurs at subfreezing temperatures. Many clouds contain supercooled water droplets, sometimes at temperatures far below freezing. Eventually the ice particles fall as snow (which will change to rain if the lower levels of the atmosphere are above freezing). Enhancing either of the two processes of precipitation formation can lead to more efficiency in producing rain or snow from a cloud. Some natural clouds appear to be deficient in ice forming nuclei; those clouds offer an opportunity to assist the rainmaking process.

Cloud Seeding Agents. Certain materials have

This inflatable dam is owned by Alameda County Water District.

been found effective in converting supercooled water droplets into ice crystals. Commonly used seeding agents for this purpose are silver iodide and dry ice. Some other chemicals also work, including some organic compounds. Hygroscopic materials such as salt, urea, and ammonium nitrate have been used in warmer clouds to assist the coalescence process.

Dry ice was frequently used in early cloud seeding programs in the United States in the 1950s and early 1960s. A switch to silver iodide occurred in the mid-1960s, probably because of more convenient storage and dispensing capabilities (dry ice applications are limited to airborne delivery systems). Dry ice has received increased attention in recent years due to its low cost and high effectiveness.

Silver iodide has been the preferred seeding agent in the majority of cloud seeding programs in the United States. Particles of silver iodide are usually produced through a combustion process followed by rapid quenching which forms trillions of effective freezing nuclei per gram of silver iodide consumed. Cloud seeding by silver iodide can be carried out using ground-based or aerial generators.

Liquid propane is a freezing agent much like dry ice. Liquid propane has the advantage of working at higher temperatures, up to a degree or two below freezing, whereas silver iodide is not very effective when temperatures are warmer than -5^0 C. Dispensing is limited to ground-based systems because it is a flammable substance. Liquid propane sprayed into the atmosphere chills the air to temperatures well below 0^0 C. As temperatures approach -40^{o}C, water vapor in the air rapidly condenses into trillions of cloud droplets which immediately freeze and grow into tiny ice crystals. Propane is used operationally in clearing supercooled fog from airports in Alaska and the northern portion of the continental U.S.

Pseudomonas syringae, a bacterium thought to reduce frost damage in plants, has been shown to be an effective nucleating agent. Use of this bacterium as a seeding agent has been limited to producing snow in ski resorts, although there have been some experiments with aerial applications.

Cloud Seeding Delivery Systems. Commonly available aircraft can be modified to carry an assortment of cloud seeding devices. Silver iodide nuclei dispensers include pyrotechnic dispensers and models that burn a solution of silver iodide and acetone. In the burning process, a typical silver iodide-acetone solution is forced through the nozzle into a combustion chamber where it is ignited, and the silver iodide crystals formed through combustion are expelled into the atmosphere. Pyrotechnics are similar to ordinary highway flares. Pyrotechnic flares impregnated with silver iodide can be mounted on aircraft, burned, and dropped into the clouds. Dry ice is frequently dispensed through openings through the floor of aircraft modified for cloud seeding. Types of aircraft used in operational cloud seeding programs range from a single engine aircraft to larger twin engine aircraft.

The most common type of ground generator consists of a solution tank which holds the seeding agent. Other components include a means of pressurizing the solution chamber, dispensing nozzles, and a combustion chamber. Frequently, such systems employ a propane tank with a pressure reduction regulator to pressurize the solution tank, as well as to provide as a combustible material into which the silver iodide-acetone solution is sprayed. Other systems utilize nitrogen to pressurize the solution tank. Pyrotechnics are also used at surface sites. Ground generation systems have been developed which are operated manually or by remote control.

Effectiveness. Although precise evaluations of the amount of water produced are difficult and expensive to determine, estimates range from 2 to 15 percent increase in annual precipitation, depending on the number and type of storms seeded. In 1992, both the American Meteorological Society and the World Meteorological Organization issued policy statements cautiously supportive of the effectiveness of weather modification efforts under the proper circumstances.

Long-Term Weather Forecasting

California's experience with flood and drought cycles demonstrates that significant economic benefits would result from the development and application of successful long-term weather forecasting capabilities. With the ability to predict weather patterns in an accurate and timely manner, water resources managers could plan for and mitigate losses associated with floods and droughts.

During the 1980s, research on ocean and atmospheric interactions in the tropical Pacific Ocean produced new and significant insights into the predictability of the so-called El Niño Southern Oscillation cycle. New weather forecasting capabilities developed through research on ENSO suggest potential applications in addressing water resources management issues.

Climate researchers at Scripps Institution of Oceanography are engaged in several efforts to provide experimental climate forecasts up to twelve months in advance. One of these efforts is focused on the use of climate forecasts to improve California's use of its scarce water resources. Scripps is leading a team of University of California scientists to downscale global climate predictions to describe impacts on local water supplies. See Chapter 3 for a discussion on climate variability.

Environmental Water Use Technologies

Wetlands Management

Wetland plants have been found to remove selenium from water applied to them. University of California, Berkeley, researchers are experimenting in the Tulare Lake Drainage District with wetland plants irrigated with high-selenium drain water in flow-through cells. Careful management of such facilities to remove selenium while avoiding food chain concentrations may result in developing safe operating criteria for wetlands supplied with agricultural drainage water. This may provide another alternative for drainage water management. (Drainage water not used to support wetlands would still have to be disposed of by other means, such as evaporation ponds.)

Real-Time Water Quality Management

One of the actions identified in the 1995 SJRMP plan was establishing a real-time water quality monitoring network for the San Joaquin River, to support water management decisions. The monitoring network collects water quality and quantity data for input to a computer model that forecasts water flow and quality along the lower San Joaquin River.

A goal of the real-time monitoring network is to enable water managers to meet San Joaquin River water quality objectives more often and more efficiently. For example, information provided by the network can support decisions related to reservoir releases at New Melones.

A recently completed demonstration project added instrumentation sites, developed analytical tools to collect and process the data, and disseminated weekly forecasts of daily San Joaquin River flow and salinity at Vernalis. In 1997, CALFED approved Category III funding to implement a two year program to expand the monitoring network. The program is scheduled to begin in fall 1998.

Fish Screen Technologies

State of the Art. Fish screens on water supply diversions protect fish from potential entrainment losses. A properly designed fish screen, with appropriate sweeping velocities past the screen, allows diversions to occur (even when juvenile fish may be present) without causing unacceptable fish losses. Fishery and water interests have been working together for several years to improve existing screens and add them to older diversions that lack screens.

NMFS and DFG have mandates for the installation and operation of fish screens. If a new diversion is installed or significant changes are made to an existing intake, a new fish screen is usually required. DFG has established a prioritized list of diversions that should be screened based on potential fish losses. Protecting the most significant diversions first will help achieve fish protection goals with the available financial resources. Programs to financially assist diverters in the installation of such screens are available through the CVPIA's AFRP, CALFED's ecosystem restoration program, the Natural Resources Conservation Service, and provisions of Proposition 204.

Current fish screen technology reflects criteria established by NMFS and DFG. Physical screens, combined with low approach velocities and proper cleaning systems, can effectively protect fish greater than about 1 inch long. Conventional screens will not protect smaller or larval-sized fish which may be present at some sites for limited durations.

Smaller pumped diversions (slant or vertical pump installations on a river with flows less than 40 cfs) generally use bolt-on screens available from a variety of manufacturers. These screens are similar to those used to reduce debris in sprinkler irrigation systems. Depending on the site and the system, screens may be made of corrosion resistant woven wire, perforated plate, or wedge-wire material (well screen). These materials can be formed into cylindrical shapes or flat plate panels and designed into the intake system.

The number of sites with fish screens (or fish passage improvements) has increased with the availability of public funding assistance (Figure 5-1). For example, the Maxwell Irrigation District now operates a state-of-the-art positive barrier fish screen, one of the first of its kind installed on the Sacramento River. Completed in 1994, the new pumping plant and screen

In February 1998, two large cylindrical fish screens were installed at one of the largest Delta diversions on Sherman Island.

facility diverts approximately 80 cfs at a completed cost of nearly $1.6 million. The screens are intended to protect all fish, but primarily steelhead and winter-run chinook salmon. In 1994, Pelger Mutual Water Company completed construction of its new pumping station and positive barrier fish screen near Knights Landing on the Sacramento River. The facility includes pumps with a discharge capacity of 60 cfs and was completed for a total cost of $350,000.

Larger diversion sites are screened with low approach positive velocity barrier screens. These intake screens may include significant civil works and are often off the main river channels where they must provide fish handling and bypass systems. These facilities require more attention to hydraulic conditions than smaller intake screens.

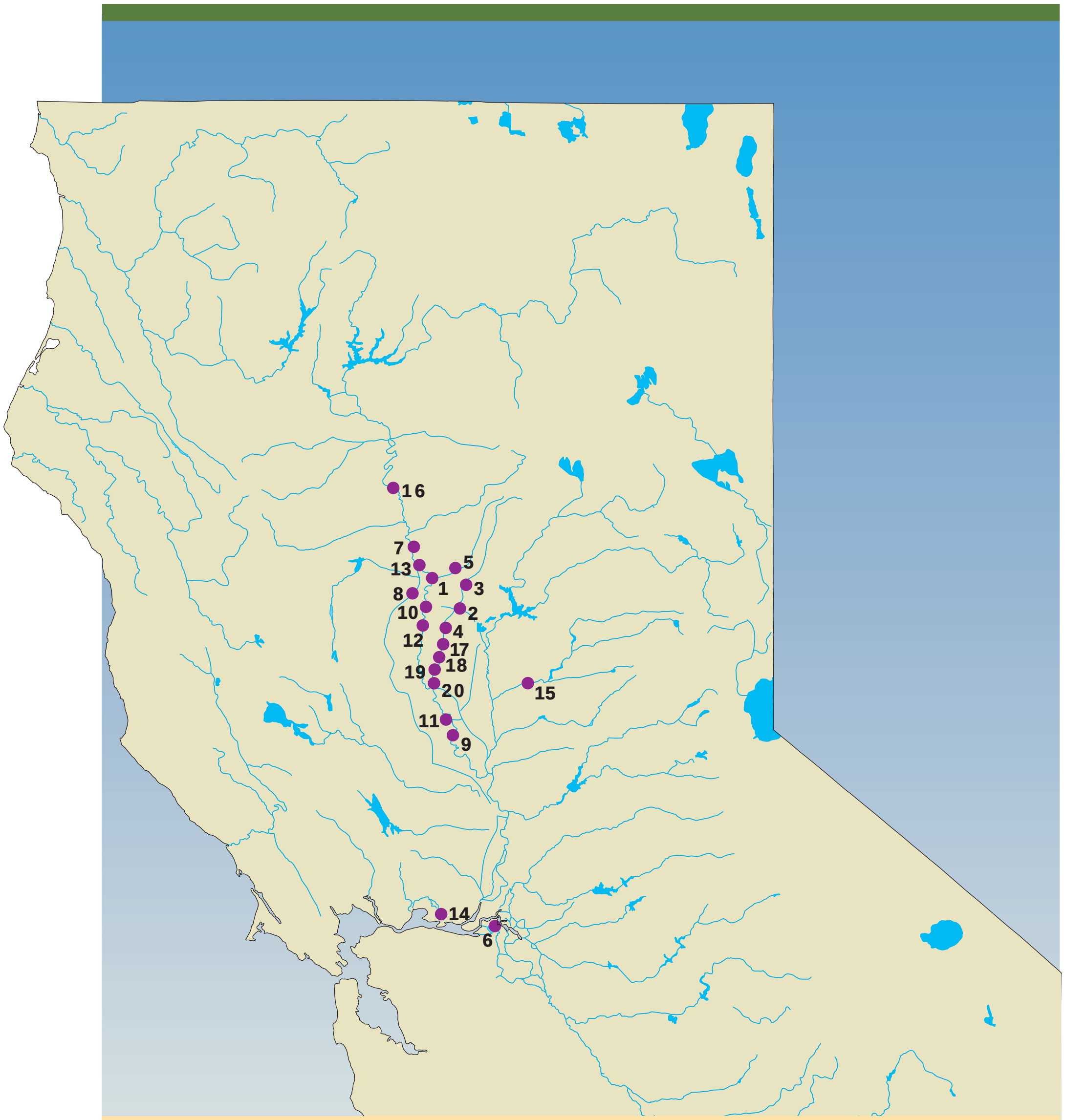
A newly constructed fish passage and screening facility on Butte Creek.

Several recently constructed facilities have been designed to current regulatory criteria for screening, including screens at the M&T Chico Ranch diversion on the Sacramento River, the Parrott-Phelan diversion on Butte Creek, and the Tehama-Colusa Canal. As part of its environmental restoration activities, M&T Chico Ranch relocated its screened pump station from the mouth of Big Chico Creek to the Sacramento River. This $5 million project provides water supply to over 8,000 acres of permanent wetlands and over 1,500 acres of seasonal wetlands, in addition to protecting habitat for migrating spring-run chinook salmon.

Several large facilities are nearing the final phases of design or construction. They include diversions on the Sacramento River at the Glenn-Colusa Irrigation District, Reclamation District 108 near Grimes, Reclamation District 1004 near Princeton, Princeton-Codora-Glenn Irrigation District and Provident Irrigation District consolidated diversion, Browns Valley Irrigation District diversion on the Yuba River, and others. Construction of GCID's Hamilton City Pumping Plant screen began in spring 1998. This $70 million project will minimize fish losses near the pumping plant and will maximize GCID's capability to divert its full irrigation supply. Reclamation District 108 began construction in 1997 on a new $10 million

FIGURE 5-1

Recent Structural Fishery Improvements



1 Sacramento River - M&T Chico Ranch, 1997
2 Butte Creek - Adams Dam, 1998
3 Butte Creek - Durham Mutual Dam, 1998
4 Butte Creek - Gorrill Dam, 1998
5 Butte Creek - Parrott - Phelan, 1996
6 Rock Slough - Contra Costa Canal, 1998
7 Sacramento River - Glenn-Colusa ID, 1998
8 Sacramento River - Maxwell ID, 1994
9 Sacramento River - Pelger MWC, 1994
10 Sacramento River - Princeton - Codora - Glenn ID/Provident ID, 1998
11 Sacramento River - RD 108, 1998
12 Sacramento River - RD 1004, 1998
13 Sacramento River - Wilson Ranch, 1995
14 Suisun Marsh - Five Projects, 1996-1997
15 Yuba River - Browns Valley ID, 1998
16 Tehama - Colusa Canal, 1990
17 Butte Creek - Western Canal WD Dams, 1998
18 Butte Creek - Point Four Diversion Dam, 1993
19 Butte Creek - McGowan Dam, 1998
20 Butte Creek - McPherrin Dam, 1998

fish screen. The project, located at the district's Wilkins Slough diversion, will protect migrating winter-run chinook salmon and other fish. The district anticipates completing the project by the 1999 irrigation season. Reclamation District 1004 began construction of its $8 million fish screen in 1998. The project includes relocation of the Princeton Pumping Plant and conveyance facilities, in addition to a positive barrier fish screen. In 1998, the Princeton-Codora-Glenn and Provident irrigation districts are expected to complete construction of an $11 million fish screen and pump consolidation project. The 600 cfs project eliminates three unscreened diversions.

Current Research. There is significant research and experience in fish screen technology. The technology has responded to a number of factors including ESA requirements in the Northwest and in California for the protection of salmonids, FERC relicensing requirements, and the heightened awareness of fish losses at diversions.

Research can be broken down into two categories: positive barrier technologies and behavioral barrier technologies. Although physical screens are considered state of the art, and are acceptable to the resource agencies, behavioral barriers have been demonstrated to deter fish from being diverted at some sites and may offer enhanced fish protection at even physically screened sites.

This circular flume, called the fish treadmill, simulates the hydraulic conditions that fish may encounter in the Delta. DWR's three year treadmill study began in 1997.

Several significant applied research projects are under way on positive barrier technologies. A research pumping plant has been constructed at the USBR's Red Bluff Diversion Dam to divert Sacramento River water into the Tehama-Colusa Canal. This facility (see photo, Chapter 2) was developed to provide water to the Tehama-Colusa Canal when the diversion dam gates are raised for fish passage. The research pumping plant is testing centrifugal and Archimedes screw pump technologies to evaluate their impacts on fish. The research plant and the biological evaluations of its effectiveness now being carried out are providing valuable data on the potential application of these technologies to other sites.

Since the early 1950s, fish screen design criteria have been developed for juvenile salmon and a few other anadromous species. Little is known about the screening requirements for resident Bay-Delta species (such as smelt) which require protection. Through a cooperative interagency program effort, a large circular screened testing flume has been constructed at University of California at Davis to investigate fish performance and behaviors under various hydraulic conditions. This research will improve understanding of the needs of fish and help design more effective screens.

Screen cleaning and proper operation and maintenance are essential for the reliability of diversion and fish protection. In the last 10 years, cleaning technologies have advanced in response to possible zebra mussel invasions and clogging from aquatic weeds. Combinations of hydraulic and air backwash systems, improved horizontal and vertical brush cleaners, and automated controls have proven effective. Screen materials and coatings have also been developed to prevent biofouling. Some investigations under way include USBR's Tracy Pumping Plant Fish Facility Improvement Program, Contra Costa Water District's new Los Vaqueros and proposed Rock Slough fish screens, and an investigation of air cleaning systems by USBR.

Higher velocity fish screens, which reduce exposure to the screen surface, are being studied. These systems are potentially less expensive because of the reduced screen area required. Modular systems are being developed for wider application. Advances in

Behavioral Barrier Demonstration Projects

Several behavioral barrier demonstration projects have been evaluated in the Central Valley.

Georgiana Slough Acoustic Barrier

Juvenile salmon survival has been shown to improve significantly if salmon are allowed to remain in the Sacramento River rather than being drawn into the central Delta via Georgiana Slough. Physical barriers and screens have been considered at this site, but are not feasible because of hydraulic conditions, water quality, recreational uses, and adult fish migration issues. A behavioral system is being studied which would improve fish survival by guiding them away from the hydraulic influence of Georgiana Slough. Twenty-one underwater acoustic speakers were installed at the Sacramento River's junction with the Slough below the town of Walnut Grove. Studies in 1993, 1994, and 1996 showed improved guidance during low flows, but mixed results at higher flow conditions. Results have been encouraging enough to continue investigations at this site under low flow conditions. Adverse effects of acoustic system operation have not been observed.

Reclamation District 108 Acoustic and Electrical Barrier

At this major Sacramento River diversion (700 cfs diversion capacity) near Grimes, acoustic and electrical barriers were tested to see if these technologies could reduce fish losses. Tests were conducted at the site from 1993 until 1996 with mixed results. The acoustic system was suspended from the surface and operated on an on/off cycle to test its effectiveness. The electrical array was mounted to an underwater louver array and was similarly evaluated. Since neither system achieved the required reduction in fish entrainment, RD 108 is constructing a positive barrier fish screen.

Reclamation District 1004 Acoustic Barrier

A similar acoustic barrier was installed at RD 1004's diversion on the Sacramento River near the town of Princeton. From 1994 to 1995, the system was evaluated and found to have marginal benefits. RD 1004 is installing a 360 cfs positive barrier fish screen at its diversion site.

Behavioral Research at Other Sites

The use of low frequency "infrasound" systems and the use of lighting systems (strobe lights) is under investigation at several sites outside of California. Many of these systems are being tested and used with other screening technologies to attempt to improve their effectiveness in difficult hydraulic environments.

automation and control systems are being used to regulate screens' hydraulics and operations and provide better fish protection and diversion reliability.

Technological advances have renewed interest in acoustic and electrical fish guidance systems. In the past, these systems have had limited success affecting fish behavior. Some guidance and protection had been observed, but the systems could not achieve the level of protection desired by State and federal resource agencies. Fish responses to behavioral technologies are variable since they may respond to other environmental stimuli, including hydraulic conditions, temperature, predator avoidance, and lighting conditions. Behavioral barriers are attractive in some cases because physical barriers may not be viable or cost-effective.

Temperature Control Technology

Temperature control technology is used to manage temperature of reservoir releases to improve conditions for downstream fisheries. During summer months, reservoir temperature gradients result in warmer water near the surface of a reservoir, with cooler water remaining near the bottom. Two types of temperature control devices are currently being used in Northern California reservoirs: variable-level outlets that permit temperature selective releases, such as USBR's Shasta Dam TCD; and temperature control curtains, such as those at Whiskeytown and Lewiston Reservoirs.

Temperature Control Devices. Some dams, such as the Department's Oroville Dam, were constructed with temperature-selective reservoir release capability. Retrofits to reservoir outlets can be constructed for those that were not, such as USBR's Shasta Dam. USBR completed the Shasta Dam TCD in May 1997, and is now fixing leakage problems that affect operation of the device. The structural steel shutter device is 250 feet wide by 300 feet high and encloses all five penstock intakes on the dam. The shutters allow for selective withdrawal of water, depending on downstream temperature needs. Prior to installation of the structure, USBR had to bypass Shasta powerplant to provide water of adequate temperature. Installation of the TCD will provide USBR with the flexibility to provide optimal water temperature downstream for the salmon fishery, and allow for hydropower generation.

Temperature Control Curtains. Curtains can control water withdrawal at intake or outlet structures to provide desired temperatures for salmonids and other aquatic species, allowing water to be conserved for other uses. Four temperature control curtains have been installed by USBR, two in Lewiston Reservoir (in 1992), and two in Whiskeytown Reservoir (in 1993). These curtains are constructed of Hypalon, a rubberized nylon fabric. They are supported in the water column by steel tank floats and anchored to stay in place.

At Lewiston Reservoir, an 830-foot-long, 35-foot deep curtain is suspended from flotation tanks and secured by a cable and anchor system. This curtain was designed to block warm surface water from the Clear Creek Tunnel intake. As a result, cold water from the bottom of the reservoir is diverted to Whiskeytown Reservoir. A second curtain was installed around the Lewiston Fish Hatchery intake structure to allow warmer or colder water, depending on the season, to be taken into the hatchery. The curtain, 300 feet long by 45 feet deep, was designed to either skim warmer water or underdraw cooler water, depending on whether the curtain was in a sunken or floating position.

Ideally, cold water diverted from Lewiston should be routed through Whiskeytown's hypolimnion (deep, cold water layer) into the Spring Creek Conduit intake. To accomplish this, two curtains were installed: a tailrace curtain downstream at Carr Powerplant, and an intake curtain surrounding the Spring Creek Conduit intake. The tailrace curtain (600 feet long and 40 feet deep) was installed to force cold water from Carr Powerplant into Whiskeytown's hypolimnion with a limited amount of mixing with the epilimnion (warm surface water). This curtain restrains warm surface water from moving upstream toward Carr Powerplant. With the tailrace curtain in place, mixing is reduced where the density current plunges into the hypolimnion upstream of the tailrace curtain. The second curtain (a 2,400-foot long, 100-foot deep, surface-suspended curtain) surrounds the Spring Creek Conduit intake. This curtain, like the Lewiston curtain, was designed to retain warm surface water while allowing only cold water withdrawal.

The temperature curtains at Lewiston and Whiskeytown Reservoirs reduce the temperature of Trinity River diversions to the Sacramento River by as much as 5^0 F. According to USBR, this decrease is significant, making the temperature curtains a successful tool for conserving reservoir releases.

The smaller temperature control curtains generally cost about $1,000 per foot. The large curtain at Whiskeytown Reservoir cost about $1.8 million. The expected duration of use is about 10 years before replacement may be required. To date, none of the four curtains in place at these two reservoirs has needed major repairs.

A number of studies are ongoing to better refine the curtains' use for temperature control, and to ensure that no adverse impacts result to biological resources in the reservoirs where they are installed.